Cortical Dynamics and Awareness State: An Interpretation of Observed Interstimulus Interval Dependence in Apparent Motion.

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Abstract

In a recent paper on Cortical Dynamics, Francis and Grossberg raise the question how visual forms and motion information are integrated to generate a coherent percept of moving forms? In their investigation of illusory contours (which are, like Kanizsa squares, mental constructs rather than stimuli on the retina) they quantify the subjective impression of apparent motion between illusory contours that are formed by two subsequent stimuli with delay times of about 0.2 second (called the interstimulus interval ISI). The impression of apparent motion is due to a back referral of a later experience to an earlier time in the conscious representation.

A model is developed which describes the state of awareness in the observer in terms of a time dependent Schroedinger equation to which a second order time derivative is added. This addition requires as boundary conditions the values of the solution both at the beginning and after the process. Satisfactory quantitative agreement is found between the results of the model and the experimental results.

We recall that in the von Neumann interpretation of the collapse of the quantum mechanical wave-function, the collapse was associated with an observer's awareness. Some questions of causality and determinism that arise from later-time boundary conditions are touched upon.

1 Experimental Background

We consider phenomena in cognitive psychology variously known as "apparent movement" [1], temporal "binding" ([2], [3]),"filling in" [4] or "coherence" [5].

It was noted several years ago that when a bright spot on a screen was followed (after an interval of up to half a second) by another spot some distance away, the viewer perceived the spots as though performing a continuous motion [6]. The time delay involved is much longer than the characteristic delay or inertial time (tens of milliseconds) in cortical neural cells and it is regarded as due to the time needed for conscious processing. Moreover, having perceived the second spot, the viewer does not "date" the motion to the instant of her seeing this, but to the instant of observation of the first spot. In the words of an authoritative source [7] [with added context-setting by us]: "... there is a subjective referral of timing [8], i.e. the brain compensates for [the] preconscious processing [what happens before $t = 0$] by "marking" the time of arrival of stimuli at the cortical surfaces [at $t = 0$] with an evoked potential and then referring experienced time of occurrence [$t = T$] back to time of arrival of stimuli [$t = 0$]. Therefore experienced [!] time of arrival is actual time of arrival [$t = 0$], rather than the time when a conscious representation has had time to develop."

It is reasonable to assume that a quantification of awareness variables (the "qualia") is feasible and access to them exists through psychological and neurobiological inquiries ([9], Section 4.3). Arguments have also been made for the existence of awareness units, analogous to atoms in matter. [10] Estimates of the speeds of mental processes, e.g. decision times ($0.06 - 0.17$ s) have been obtained in the classic studies of Donders [11]. These are distinct from the times needed for "neural conditions to develop that are adequate to support conscious experience" [7] and presumably relate to processes in upper layers of the cortex.

2 Wave-function formalism

We describe cognitive processes in terms of brain (r) and **awareness** (A) variables and assume that their combined state $\Psi(r, A; t)$ (t is time) is subject to the formalism of wave mechanics. This hinges on a Hamiltonian $H(r, A; t)$ which prescribes the evolution of the state of cognition. Since, however, Schroedinger equation is completely causal (in the sense that its solution evolves in time in a unique manner), whereas mental processes are (by our understanding) non-deterministic, we write the following equation for $\Psi(r, A; t)$.

$$-W\frac{\partial^2\Psi}{\partial t^2} + ih\frac{\partial\Psi}{\partial t} = H\Psi. \tag{1}$$

Since this is a **second** order differential equation in time, its solutions are fixed by boundary conditions imposed on Ψ both at the beginning and at the **end** of the cognitive process. This type of boundary conditions is appropriate for the description of human choices and decisions (which are **felt** to be non-predestinated) and for the collapse of wave packets in the course of a quantum mechanical measurement (whose outcomes are also not predetermined). [We note that the original form of the non-relativistic limit of the Dirac equation also has a second order time-derivative, rather than only the first order derivative, as in the Schroedinger equation.[12]] In simple

terms this means that in order to describe certain mental processes one has to know (in addition to the "mechanism", expressed by the Hamiltonian) the final as well as the initial state. The probability (or frequency) of a final state actually occurring is given by Born's propensity rules.[Exactly as in quantum mechanics (Probability $\propto$ weight of final state in the initial state).]

3 Awareness state

For constant H one can solve equation (1) in the domain (called "Domain II") between $t-0$ and T, with boundary conditions imposed at the edges of the domain. For $\frac{HW}{\hbar^2} \gg 1$ [which is appropriate for brain sizes having macroscopic (not atomic) dimensions] one obtains solutions of the type:

$$\Psi = a \exp t\sqrt{\frac{H}{W}} + b \exp -t\sqrt{\frac{H}{W}}. \tag{2}$$

The norm of this state function is time dependent and has a minimum at the midpoint of the domain (at $t = T/2$) of about

$$|\Psi|^2_{min} = \exp -T\sqrt{\frac{H}{W}}. \tag{3}$$

Because of the conservation of all matter in the brain, the natural interpretation of this result is that awareness is **not** conserved but dips inside domain II. To test this in a specific, but still hypothetic way we turn to observation of apparent motion between illusory contours [13]. This phenomenon was recently quantitatively investigated by Francis and Grossberg [1], who obtained the percentage of positive responses from two subjects (GM and PG) as function of stimulus duration D (in the range $0.04 - 0.64$ s) and of the interstimulus interval (ISI) in the same range (Their figure 1(a)). We identify the perception of motion with the arousal of awareness and the ISI with our parameter T. We further suppose that there is a threshold of awareness intensity given by some value of the state function squared $l_0 = |\Psi_0|^2$ below which the apparent motion will not be perceived (i.e. the subject will say he has not seen any motion). For simplicity we shall make a further assumption (similar to the ergodic hypothesis); namely, that the fraction of times that the subject will give a positive answer will be equal to that fraction of time length within domain II during which the state function intensity exceeds the threshold; or to the fraction of time that

$$|\Psi(t)|^2 > l_0. \tag{4}$$

Approximating $|\Psi(t)|^2$ in the region $0 < t < \frac{T}{2}$ by a simple exponential:

$$\exp -2v_+t \tag{5}$$

and in the region $\frac{T}{2} < t < T$ by its mirror image (so that $|\Psi|^2$ is unity at $t = 0$ and T), we obtain for the fraction of time $f(T)$ that equation (4) is satisfied:

$$f(T) \quad = \quad \frac{\log\frac{1}{l_0}}{v_+T} \qquad \text{if} \quad \frac{\log\frac{1}{l_0}}{v_+T} \leq 1.$$

Subject	D	Value	0.85	0.7	0.55	Average	s.d.
GM	160	ISI	196	251	310		
		$ISI \times Prob.$	167	176	171	171	4.5
GM	320	ISI	209	282	361		
		$ISI \times Prob.$	178	197	199	191	11.6
GM	640	ISI	187	238.5	293		
		$ISI \times Prob.$	159	167	161	162	4.2
PG	160	ISI	377	490	624		
		$ISI \times Prob.$	320	343	343	335	13.3
PG	320	ISI	343	422	505		
		$ISI \times Prob.$	291	295	278	288	8.9
PG	640	ISI	175	258	353		
		$ISI \times Prob.$	149	181	194	175	23.2

Table 1: Values of Interstimulus Intervals (milliseconds) at which subjects GM and PG perceived motion with shown probabilities (relative frequencies) at given values of stimulus duration (D, in ms). From Francis and Grossberg [1]. Adjacent rows show the computed products $ISI \times Probabilities$ and their averages for each row and the standard deviations (s.d.). The theory states that $ISI \times Prob.$ is a constant in each row.

$$f(T) \quad = \quad 1 \qquad \text{if} \quad \frac{\log \frac{1}{l_0}}{v_+ T} > 1. \tag{6}$$

We wish to test this $f(T)$ vs. T against the probability vs. ISI values of Francis and Grossberg [1]. Neither l_0 nor v_+ are known and indeed may vary with subject and D (stimulus duration), but we see from equation (6) that for a given subject and D $f(T)T$ is independent of T or of $f(T)$.

The following table (Table 1)exhibits the values for

$$ISI \times Probability \tag{7}$$

at three equi-spaced values of $\log D$ and for both subjects, taken from the contour plot of Francis and Grossberg [1]. The constancy of the product in 7 is indeed apparent. To better appreciate this, we show the averages and the standard deviation (s.d.) of the product of each case. The s.d. are much smaller (11 is the mean s.d.) than the deviation between the averages (the maximum deviation of averages in Table 1 is 170 and the root mean square of the differences between the 6 averages is 106).

4 Conclusion

This work has started out with a simple idea that intended to fill in a gap in the conventional formulation of Quantum Mechanics, namely to describe the reduction of the wave-packet as a continuous time-varying process. The second order differential

equation (1) , together with its boundary conditions, does this. Questions arising from it (e.g., nonunitarity of development, causality) are not harder than those for previous works,e.g. the two-time formalism of Aharonov and co-authors. An interpretation of the awareness state function has been discussed in section 3.

In the awareness interpretation, the collapse is an expression of the mind-brain interaction and the collapse-equation proposed in this work is a formalization of this interaction. When we extend the reign of the equation to cognitive processes in general, we find novel implications in the following fields: The psychological phenomenon of back referral (see section 3), the quantification of conscious activity in small species , the process of mental decisions and the issue of free will .

As the a next step, one needs to devise some critical experiments whereby the theory can be tested.

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